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955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

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date: September 30, 1971

to: Distribution

from: S. H. Levine

subject: In-Flight Calibration of Apollo Telescope Mount Experiments Operating in the Vacuum Ultraviolet (VUV) Wavelength Range - Case 620

ABSTRACT

The need for calibration of ATM ultraviolet experiments is discussed and methods of performing in-flight calibration of ATM Experiments S082A, S082B, and S055 are examined.

Data are presented that identify contributing elements to degradation of experiment results, namely:

1. Optical degradation due to contamination
2. Film degradation due to radiation, temperature and normal aging processes.
3. High vacuum effects on experiment detectors.

The conclusions that are reached are:

1. Absolute and relative intensity calibration for these experiments is necessary based upon the large data uncertainties that are time and wavelength related.
2. In-flight calibration of these experiments using other Skylab experiments or instrumentation or standard sources and detectors is either not feasible or not practicable at this time. Real-time undegraded calibration data points using rocket instruments appears to be the only reliable technique available and practicable.

(NASA-CR-123226) IN-FLIGHT CALIBRATION OF APOLLO TELESCOPE MOUNT EXPERIMENTS OPERATING IN THE VACUUM ULTRAVIOLET /VUV/ WAVELENGTH RANGE (Bellcomm, Inc.) 45 p

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CR-123226

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

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3. Examination of a tradeoff between resupply of experiment optical elements and detectors, use of calibration rocket instruments, and development of a standard UV source for orbital application on future manned space flight programs appears to be a worthwhile consideration.

4. Consideration should be given to leaving some of the contamination sampling devices in the ATM through launch, to be recovered by EVA at selected time(s) in the mission. This would provide additional data points on internal contamination with virtually no perturbation to the program.

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MEMORANDUM FOR FILE

A study was conducted to examine methods of performing in-flight calibration of Apollo Telescope Mount (ATM) ultraviolet experiments. ATM ultraviolet (UV) wavelength experiments include the S055 - Harvard College Observatory UV Polychromator-Spectroheliometer operating in the range of from 300 to 1400Å, the S082A Naval Research Laboratory Coronal Extreme UV Spectroheliograph operating between 150 and 625Å, and the S082B Naval Research Laboratory Chromospheric XUV Spectrograph which operates in the wavelength range of between 970 and 3940Å.

Attachment I presents in general form:

1. The need for periodic calibration of VUV experiments

2. Methods of calibrating experiments

3. A survey of ultraviolet illumination sources for calibration, and

4. Conclusions and recommendations.

The discussion that follows provides background information and explanation of the presentation material in Attachment I. This study does not address the subject of calibration rocket instruments or launch vehicle requirements, nor does it address the requirement for qualification rocket flights for the proposed ATM calibration instruments.

UV Absolute Intensity Measurements

Attachment I delineates the goals, wavelength ranges, optical materials, and detectors associated with the S055 and S082 experiments.

Equations are shown that identify the parametric relationships used to describe the physical characteristics of the Sun.[10] It can be easily seen that knowing the absolute intensities and the wavelength distribution of observed phenomena in the solar atmosphere, much can be learned in understanding the makeup and physical processes of the Sun.

Reeves[3] and Tousey[13] have placed the required accuracy of absolute intensity measurements roughly between 10 and 20% at about 1300Å, to adequately confirm solar energy balance theories and to properly interpret solar structure and mechanisms.

It should be pointed out that in 1965 the National Academy of Arts and Sciences - Space Science Board stated,[12]

> "The solar intensity distribution is thought to be determined from photographic spectra with an absolute accuracy of ±10% from 3000 to 2500Å. At shorter wavelengths the accuracy gradually deteriorates to perhaps ±20% and to ±50% at 1300Å ..."
>
> "From 900 to 170Å, the most accurate measurements are those of AFCRL (Hintereggar, et al.) made photoelectrically." (The accuracy in this range probably falls by about a factor of 2 or 3)

Experiment History

After manufacture of ATM UV experiment components, the experiment is assembled, checked out, calibrated against sources of known intensity and wavelength distribution, and then undergoes rigorous acceptance testing. Delivery to MSFC is followed by mounting of the experiments and other components on the ATM spar, completion of spar wiring activities, experiment checkout, and experiment alignment. The ATM experiment package canister is completed and the pointing control system gimbal rings are added to the assembly. Subsequent to these necessary processing steps, the total ATM is assembled into a functioning spacecraft and post-manufacturing checkout is performed to eliminate system "bugs" and verify that all systems are functioning properly. At this time simulated mission vibration tests are conducted at MSFC. The ATM is then shipped to MSC, where thermal vacuum tests are performed on the entire system. These tests include simulated mission tests in the presence of mission environmental extremes. Thermal vacuum tests are followed by delivery of the ATM to KSC by the "Super-Guppy" aircraft and commencement of pre-launch processing prior to and after integration with the rest of the SL-1 space vehicle.

It is estimated that at least 2 to 2-1/2 years will expire between the birth of ATM experiment hardware (i.e., fabrication and calibration of optics, etc.) and the flight of SL-1. An additional eight months of lifetime in orbit will bring the age of the system to approximately three years.

Because of the inaccessibility to experiment optics and detectors after ATM assembly and the requirement for a vacuum environment for operation in ultraviolet wavelength ranges below 3000Å, only a token check of experiment calibration drift can be performed during this complex processing of the flight Apollo Telescope Mount and this is done in the MSC Vacuum Chamber prior to shipment of the ATM to KSC.

Calibration Drift

Recovery of the absolute characteristics of the observed phenomena must be the desired objective of any scientific program. Much has been written in regard to the change of characteristics of ultraviolet experiment equipment and scientfic data with time. These changes tend to mask and distort the data obtained by the instrument and thus may lead to misinterpretation of flight results, or in severe cases, the total loss of scientific data.

Several changes in characteristics of UV instruments that have been observed and recorded during the life of scientific experiments are of particular concern to Skylab. These include:

1. Optical degradation - Optical efficiency changes occur when UV experiment optics are exposed to contamination sources, especially in the presence of ultraviolet radiation.

2. Film degradation - Sensitivity changes occur and latent images degrade in the presence of radiation, and heat, and from normal film aging processes.

3. Photoelectric sensor yield degradation - Response characteristics of photomultiplier detectors change with time in the presence of contaminants and in very high vacuum environments.

These changes are, for the most part, additive, very wavelength dependent, and not very predictable. Periodic calibrations must be performed throughout the life of the ATM ultraviolet experiments to eliminate these and other data uncertainties. Since these processes are generally non-linear, the frequency of calibration and the points at which calibration are conducted become a very important aspect in the proper adjustment and interpretation of scientific data. This is especially true when considering very long experiment lifetimes, in uncertain and generally hostile natural and induced environments, as in Skylab. Linear approximations for very widespread calibration data points may lead to unacceptable inaccuracies in the corrected experiment data.

Reflectance Changes in UV Optics

The performance of optical materials in space may degrade because of much the same environmental factors that affect other spacecraft materials. Sublimation, decomposition, and offgassing of spacecraft materials in the high vacuum environment of space ($\sim 10^{-8}$ torrs) may result in deposition of contaminants on optical surfaces and attendant degradation in reflectances of these materials. This is of particular concern in normal incidence scientific instruments (similar to S082 and S055 experiments) that operate in the extreme ultraviolet (XUV) range (between 100 and 2000Å) where optical efficiencies are very low at best. Figure 6 shows optical efficiency curves for aluminum overcoated with magnesium fluoride,[1] and for gold and platinum optics[5]. Optical elements using these types of coatings are particularly suitable for extreme ultraviolet spectroscopy because of their relatively high reflectance on the far side of the extreme ultraviolet wavelength range short of 1050Å. For all wavelengths below 1000Å the peak optical efficiency is about a factor of four lower than for wavelengths above 1200Å when using a mirror coated with $\sim$1000Å of aluminum with a 250Å magnesium fluoride overcoat ($\sim$S082 experiment mirrors).

Generally speaking, platinum or gold coated optics (Figure 6)[5] are preferred to Al+MgF_2 for wavelengths below 1000Å and are, indeed, used by HCO on the S055 experiment; however, the latter may be selected if there is too much inconvenience in changing out optics when switching experiment operation from long XUV wavelength (>1000Å) to short wavelength (<1000Å).

Reflectance measurements on contaminated XUV-type optics display marked degradation at wavelengths above 800Å when compared to measurements taken on clean optical samples of the same variety. Coupling the already low reflectance in in these lower wavelengths (approximately 20%) and the dimness of source of the sun in wavelengths below 1000Å, where the fraction of the total solar radiant energy is approximately .000001, [2] any reflectance change in the downward direction will result in significant effect on the scientific data obtained by the instrument, possibly even the total loss of important solar data. Reeves has shown that even where class 100 clean-room precautions were enforced in the storage of platinum coated optical samples, where exposure was limited to cleaned and filtered atmosphere and UV radiation over a six-month period, the reflectance dropped off by as much as a factor of 1.6 for wavelengths above 1100Å (Figure 1). It should be noted that the presence of UV radiation aggravates optical contamination by increasing the adsorption properties of the surface material. It has been shown that cleaning a surface after UV photon exposure will not restore the original optical reflectance properties of that surface. Data from OSO-IV (HCO) and OSO-V (NRL) unmanned satellite programs similarly confirms optical degradation that was attributed to contamination effects on ultraviolet optical elements. Figure 2 demonstrates the method by which optical efficiency correction curves were developed by Harvard on the OSO-IV mission. A monitor mirror of the same variety as the flight instrument's mirror was installed in the optical path of the experiment five weeks prior to flight, at the time the system was assembled. The sample mirror experienced the same environmental history as the flight system until it was removed from the experiment a few hours before lift-off. Measurements taken on the mirror sample revealed marked reflectance degradation over the data taken prior to installation on the experiment, particularly in the wavelength range above 700-800Å. It should be pointed out that since there was no access to the OSO spacecraft optics after launch, post-launch optical changes can only be inferred from total recorded data degradation that may have resulted from optical as well as other system deteriorations (e.g., signal variations, instrument response changes, duty cycle effects, fatigue effects, intermittance effects, noise internal and external to the system).

Several conclusions can be reached from close examination of Figures 1 and 2:

1. Optical degradation from contamination is wavelength dependent.

2. Major changes in the reflectance of platinum, attributable to contamination, occur at wavelengths in the UV above 800Å.

3. Even under ultraclean environmental conditions, optics may degrade. Platinum reflectance degraded substantially after six months of class 100 clean-room exposure, while ATM experiment optics will be exposed to about 2-1/2 years of class 10000 clean-room exposure.

4. Both platinum samples exhibited roughly the same level of degradation whether exposed to contamination for five weeks or six months. Assuming all other things being equal, it appears that the largest degree of degradation may occur during the first five weeks of exposure. To affirm this conclusion, of course, a larger statistical sample is required.

Precautions are being taken on Skylab to observe and return large quantities of data on the contamination environment external to a large earth orbiting manned spacecraft. The T027 experiment will return optical samples (including ATM type optics) that have been exposed to the environment near the orbital assembly (OA), a very sensitive photometer on T027 will record the light scattering environment near the OA, as will the S052 ATM coronagraph. Cold cathode pressure gauges will be mounted within ATM that will monitor pressure buildup in the ATM experiment package, and quartz crystal microbalance devices on the ATM and on the T027 experiment will measure deposition of contaminants with good time resolution. Although these instruments will provide a wealth of information about the optical environment external to the spacecraft, localized contamination effects on experiments from outgassing products and other spacecraft effluents may not be known with any great accuracy.

As in the OSO program, mirror samples will be installed within the ATM experiments package to determine the pre-flight processing effects on the reflectance of optics. The Skylab approach, however, will allow samples to be retrieved periodically, at various steps in the program, and thus should give a reasonably accurate time history of prelaunch optical contamination. Should particular phases of the processing reveal inordinately large optical degradation when compared with other phases, additional resources will undoubtedly be focused in rectifying the problem and in cleaning up the contributing elements on future programs. One further step should be taken on Skylab in acquiring data on contaminant deposition on ATM optical elements. Using the previously discussed capability for prelaunch retrieval of ATM optical contamination samples, monitor samples should be emplaced in the experiment package at the latest possible time in prelaunch space vehicle processing and removed during the normal extravehicular astronaut film retrieval activities in orbit. Extending this capability to in-flight sample retrieval would cause little impact, but would provide data that may help identify ATM localized optical degradation. This would provide information on contaminant consistencies and abundances with some time resolution. Although it would be highly desirable to incorporate such samples within the individual experiments, such implementation is not possible at this time in the program.

Yield Degradation of Photoelectric Devices

The S055A experiment will photoelectrically record solar characteristics using open channel photomultipliers of the Bendix Continuous Channel Electron Photomultiplier (Channeltron) variety. Experience on comparable experiments with similar photoelectric detecting devices on unmanned satellites has shown unpredictable degradation in photomultiplier gain that is both wavelength and time dependent.[15, 4] It has been theorized that this degradation may be linked to deposition of spacecraft outgassed products on the photocathodes of these deviced and also to the effect of prolonged exposure to the hard vacuum of space that ultimately causes a "clean-up" or "scrubbing" effect on the more weakly bound condensed contaminants.

Reeves has shown[4] that sensitivity changes occurred to the Harvard photomultiplier on OSO-IV shortly after the instrument was turned on in orbit and it continued to deteriorate until the degradation stabilized after approximately four weeks of operation (see Figure 3). Changes in sensitivity at wavelengths longer than 970Å increased by about a factor of 6 after about a week of instrument operation in orbit and then stabilized at about three times the initial level after a month of operation. For some wavelengths in the range below 850Å the photomultiplier was observed to behave in an opposite sense, the sensitivity of the instrument dropped by a factor of about six after about a week of operation and then stabilized at a level of about 3.5 below the original intensity some two weeks later. In short, the wavelength sensitivity increased at longer wavelengths and often decreased at shorter wavelengths. Hintereggar reported similar intensity degradation on OSO-III.[15]

Madden has shown[14] in the laboratory that very clean tungsten photocathodes have photoelectric yields which are sensitive to even monolayers of contamination and that different effects are exhibited by different contaminating gases (see Figure 4). Therefore, it is to be expected that the typical complex outgassing products from a spacecraft may result in dramatic changes in both magnitude and wavelength distribution of photoelectric yield. Madden's group also showed[14, 16] that the scrubbing effects of high vacuum will alter the yield of photoelectric devices coated with a stabilized layer of contamination. This cleaning effect results in substantial dropoff in photoelectron output at wavelengths below 1000Å.

As part of the Skylab Ground-Based Astronomy Program, the Optical Physics Division of the National Bureau of Standards has been awarded a contract[9] to continue investigating the effect of the removal or addition of monolayers of contaminating substances (simple hydrocarbons will be used) on the performance of tungsten photocathodes. These tests will be conducted in vacua of 10^{-10} torr, over the wavelength range of 500 to 1500Å. This study will determine the contribution of surface contaminants to the yield of photoelectric devices and should help greatly in the proper interpretation of orbital changes or in the adjustment of surface materials of similar photoelectric detectors.

Photographic Film Degradation

The NRL S082A and S082B experiments record solar phenomena on photographic film of the Kodak SWR (Short Wavelength Radiation) variety. Film response is characterized by the well-known H&D (Hurter and Driffield) curve that is a plot of the $\log_{10}$ of fogging density (or opacity) vs. the $\log_{10}$ of exposure. This familiar S-shaped curve is different for each film and is known to change in time with temperature, radiation, humidity, pressure, and age, among other things. Curve changes are represented by a rise in sensing threshold, a lateral displacement, twisting or distortions, or combinations of these effects. Figure 5 shows the types of degradation that can occur to film characteristics.[17] Such distortion to film characteristics may alter interpretation of the signal strength of the observed phenomena, change the spatial resolution of the data, or in more drastic cases completely destroy the recorded observation. Absolute calibration provides a necessary gauge for interpreting that which is genuine signal strength and that which is noise in the recorded data.

Calibration Techniques

This study was undertaken to determine whether there were means available that would allow on-board calibration of ATM UV instruments in place of a costly complex calibration rocket program.

Four basic approaches to calibration have been investigated; namely, use of:

1. Another Skylab experiment operating in the same ultraviolet wavelength range for calibrating ATM experiments,
2. A standard light source of known characteristics for calibrating ATM UV experiments,
3. A standard detector for comparison against ATM UV experiment recorded data, and
4. Fresh calibration rocket instruments observing the same phenomena and comparing recorded data with ATM UV experiment data.

Attachment I identified a general evaluation of the various approaches. The reader is directed to the literature[5,6,7,8, 18] for further information relative to the available sources and detectors since comprehensive discussion of the characteristics of these equipments would be far too detailed for this memorandum.

Some general observations can be culled from the information on calibration techniques provided in Attachment I:

1. All instrumentation on board the orbital assembly may undergo changes similar to the ATM UV experiments, in the presence of the hostile space environment and normal aging processes of the system.

2. Other UV experiments on Skylab are sufficiently different from ATM experiments from an optical and detector standpoint, to make them unusable for calibrating ATM ultraviolet experiments.

3. It is not feasible to observe stellar sources of known intensity with ATM instruments because the accuracy of the vehicle pointing control system and the sensitivity of the on-board television display is insufficient for locating a star within the field-of-view of the S055 or S082 experiments. In addition, the point source would not fill the experiment slits (5 $\widehat{\text{sec}}$ x 5 $\widehat{\text{sec}}$ for S055 and 2 $\widehat{\text{sec}}$ x 60 $\widehat{\text{sec}}$ for S082B), nor would the fixed exposure times of ATM experiments be compatible with stellar light levels.

4. Incorporation of artificial light sources internal to the ATM canister is not possible at this stage of the program. Consideration of artificial light sources external to the ATM is impractical.

5. Detector standards are not practicable because they are complicated to use, must be calibrated themselves, and require other sources and detectors for comparison.

6. No stable practical artificial sources are available that cover a sufficient UV wavelength range, are flight qualified, or are generally usable in other than the confines of a controlled laboratory. The only acceptable established standard for radiation from the XUV to the IR is the synchrotron which is a ground-based facility.

7. Absolute intensity calibration in the controlled laboratory with accepted light standards in itself is probably accurate, at best, to about 10 or 15% in the wavelength range above 1000Å.

8. The National Bureau of Standards has recently been commissioned to develop a stable Hydrogen Continium Standard that will cover the extreme ultraviolet range through to visible radiation, 500 to 5000Å, with sufficient intensity levels. This standard will, hopefully, be available for calibrating ATM UV calibration rocket experiments in the latter part of 1972 and during 1973. The feasibility of using a mature integrated version of this source for future manned space experiments operating in the ultraviolet wavelength range (e.g., Skylab B, Shuttle, etc.) should be explored. It should be pointed out that several obstacles to this approach exist, namely:

    a. The standard will degrade in orbit.

    b. The standard must be periodically calibrated.

    c. Sizable power supplies are required to support the operation of this device.

    d. The use of hydrogen is hazardous, particularly with an open-windowed free flow device, required for wavelengths below 1050Å.

e. The susceptibility to voltage breakdown of experiment high voltage power supplies in the presence of free flowing hydrogen increases markedly even with incorporation of a differential pumping system to direct the vapor flow.

A tradeoff is required that compares development and implementation of a flight ultraviolet light standard source with calibration rocket flights and also against resupply missions that include replacement of aged and degraded UV optics, photoelectric detectors, and film in lieu of UV data calibration.

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Attachments

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ATTACHMENT I

<u>ATM UV EXPERIMENTS -- FLIGHT CALIBRATION</u>

PROBLEM: STUDY THE METHODS AVAILABLE FOR CONDUCTING IN-FLIGHT CALIBRATION OF ATM UV INSTRUMENTS

S. H. LEVINE

CONTENTS

S055 - UV SCANNING POLYCHROMATOR/SPECTROHELIOMETER

OBJECTIVES

- DETERMINE TEMPERATURE CHANGES ACROSS BOUNDARIES BETWEEN REGIONS OF SUPER GRANULATION
- EXAMINE DIFFERENCES IN THE APPARENT SIZE OF THE SUN AS A FUNCTION OF WAVELENGTH
- RECORD DIFFERENCES IN LIMB DARKENING PROFILES OVER THIS RANGE OF EXCITATION ENERGIES, BETWEEN 13.6EV (HI) AND 367EV (MgX), AND DETERMINE CORONAL ION DENSITY AND DISTRIBUTION
- INVESTIGATE SPICULES AND INTERSPICULAR MATERIALS AND EXAMINE WHETHER CERTAIN INTENSITY CHANGES RESULT FROM CHANGES IN TEMPERATURE OR ABUNDANCE
- OBSERVE AND MONITOR THE TRANSITION REGION BETWEEN THE PHOTOSPHERE AND CHROMOSPHERE
- DETERMINE CENTER-TO-LIMB VARIATIONS WITHIN THE SOLAR DISK
- RECORD THE EVOLUTION OF ACTIVE REGIONS AND EVALUATE VARIATIONS IN INTENSITY OF VARIOUS WAVELENGTHS OF LIGHT OBTAINED FROM ACTIVE REGIONS ON THE SOLAR DISK
- OBSERVE WAVELENGTH DISTRIBUTION AND INTENSITIES OF FLARE ACTIVITY ON THE SUN

NRL S082A - CORONAL SPECTROHELIOGRAPH

OBJECTIVES

- Record in great spatial detail the emission pattern of the entire chromosphere and corona
- Map different layers in the solar atmosphere, by selecting the appropriate XUV lines, —obtaining solar temperature, density, and composition ("weather") maps at many heights.
- Study active regions, record their appearance at different heights. Watch them develop from day to day.
- Observe XUV emissions beyond the limb in the corona, that originate from the rear side of the sun.
- Record the development of solar flares; watch their temperatures change, see their effects propagate up through the atmosphere.

NRL S082B - CHROMOSPHERIC SPECTROGRAPH

OBJECTIVES

- Obtain in great spectral detail, the spectra of selected small isolated regions of the sun.
- Study, quantitatively, the change in the spectrum crossing from the photosphere, to the chromosphere, to the corona. Derive from this the detailed temperature and density model.
- Record flare spectra with spectral resolution much greater than S082A.
- Record spectra of special regions, and so determine their nature.

REQUIREMENT FOR ABSOLUTE & RELATIVE INTENSITIES IN XUV

ABSOLUTE ENERGY -----→
(CONTINUUM & LINE SPECTRUM)

- ELECTRON PRESSURE
- ELECTRON TEMPERATURE
- IONIZATION TEMPERATURE
- ION DENSITY
- ION PRESSURE
- DEGREE OF IONIZATION
- EXCITATION TEMPERATURES

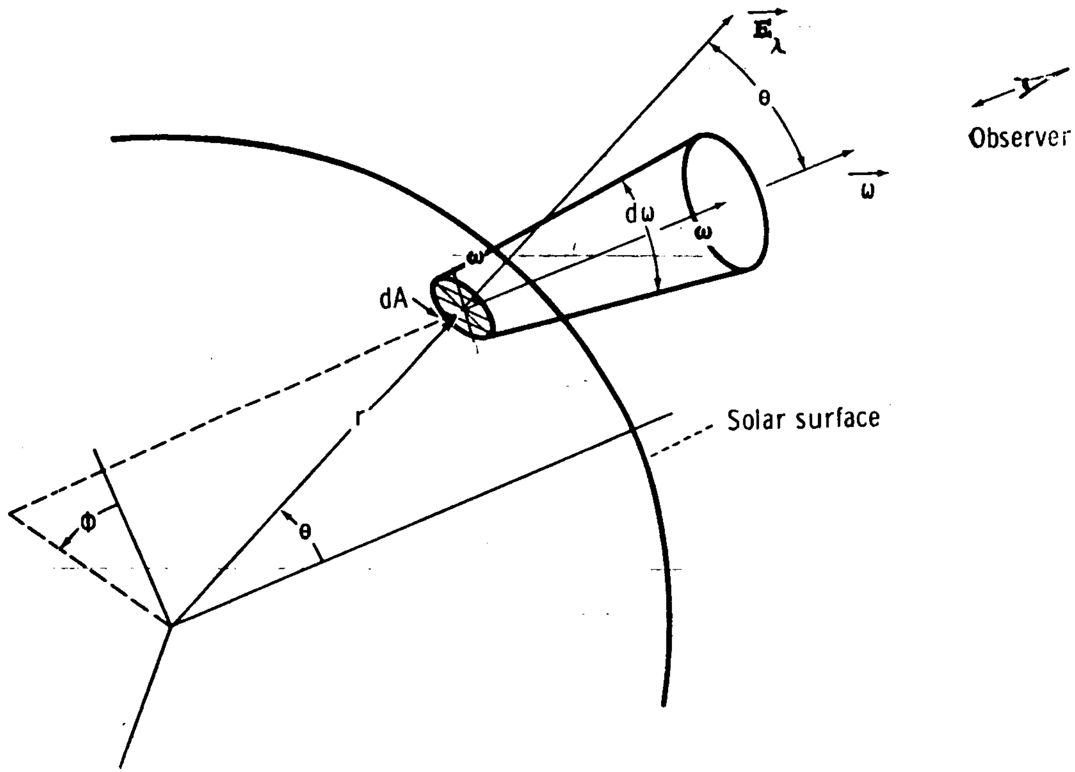
- - - - - - - - - - - - - - -

RELATIVE INTENSITY -----→
(LINE PROFILES)

- KINETIC TEMPERATURE
- MICRO- & MACRO- TURBULENCE
- LARGE SCALE MOTIONS
- COMPOSITION

SOLAR MODEL

INFO. REQUIRED



Geometric variables of specific intensity.

SOLAR MODEL -- PARAMETRIC RELATIONSHIPS

$$E_\lambda = \frac{hc}{\lambda} \; ; \; \frac{d(E_\lambda)}{dt} = I_\lambda \cos\Theta \, d A \, d\lambda \, d\omega$$

$$E_{\lambda_{BB}} = \frac{1.16\text{x}10^8 \, \lambda^{-5}}{e^{25740/\lambda T}{}_{-1}}$$ (Plancks Black Body Radiation Equation)

$$\frac{dM}{dr} = \rho \, 4 \, \pi \, r^2$$ (from mass balance equation)

$$\frac{dp}{dr} = - \frac{MG}{r^2} \rho$$ (from force balance equation)

$$\frac{dL}{dr} = \varepsilon \, \rho \, 4 \, \pi \, r^2$$ (from energy balance equation)

$$\left(\frac{dT}{dr}\right)_{\text{radiation}} = - \frac{3}{16 \, \sigma \, T^3} \frac{L}{4 \, \pi \, r^2} (\kappa\rho)$$ (Gas momentum absorption equation set equal to pressure change equation)

$$\left(\frac{dT}{dr}\right)_{\text{adiabatic convection}} = \frac{\gamma - 1}{\gamma} \frac{T}{p} \left(\frac{dp}{dr}\right)$$

---

h = Planck's constant

E = Energy

t = Time

I_λ = Monochromatic specific intensity

λ = Wavelength

c = Photon velocity

Θ = Observing angle w.r.t. limb

ω = Direction of unit area A

M = Mass

r = Radius from sun center

ρ = Density

p = Pressure

$\frac{MG}{r^2}$ = Local value of gravity

L = Luminosity or rate of energy emission from a sphere

ε = Energy production per unit mass

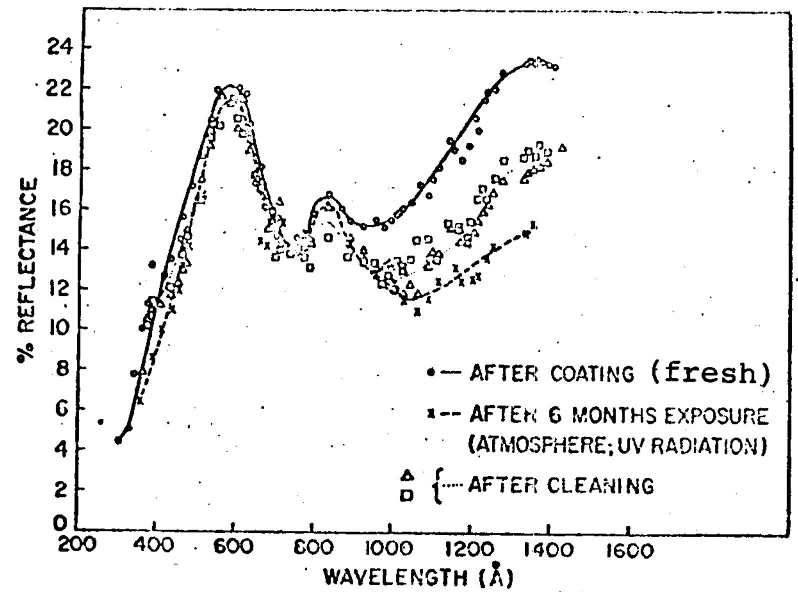
$\kappa\rho$ = Mass absorption coefficient, reciprocal of photon mean free path

σ = Stephen-Boltzmann Const.

T = Temperature

UNCERTAINTIES AFFECTING ATM UV DATA INTERPRETATION

- CHANNEL ELECTRON MULTIPLIER (S055-HCO) INTENSITY DEGRADATION
  - CONTAMINATION EFFECTS CURRENTLY UNDER STUDY AT NBS
  - DEGRADATION CITED IN LITERATURE -- HINTEREGGER, REEVES, MADDEN, ETC. -- TIME RELATED
- OPTICAL EFFICIENCY DEGRADES WITH TIME
  - CONTAMINATION EFFECTS WAVELENGTH DEPENDENT
  - CONTAMINATION EFFECTS UV EXPOSURE DEPENDENT
  - DATA AVAILABLE FROM OSO & ROCKET PROGRAMS ON PRELAUNCH CONTAMINATION OF OPTICS
- PHOTOGRAPHIC FILM VARIATIONS
  - SENSITIVITY SHIFTS DUE TO RADIATION HISTORY
  - SENSITIVITY SHIFTS DUE TO THERMAL HISTORY
  - AGING CHARACTERISTICS
  - LATENT IMAGE CHANGES DUE TO ENVIRONMENT
  - SHIFTING OF FILM CHARACTERISTICS IS WAVELENGTH DEPENDENT



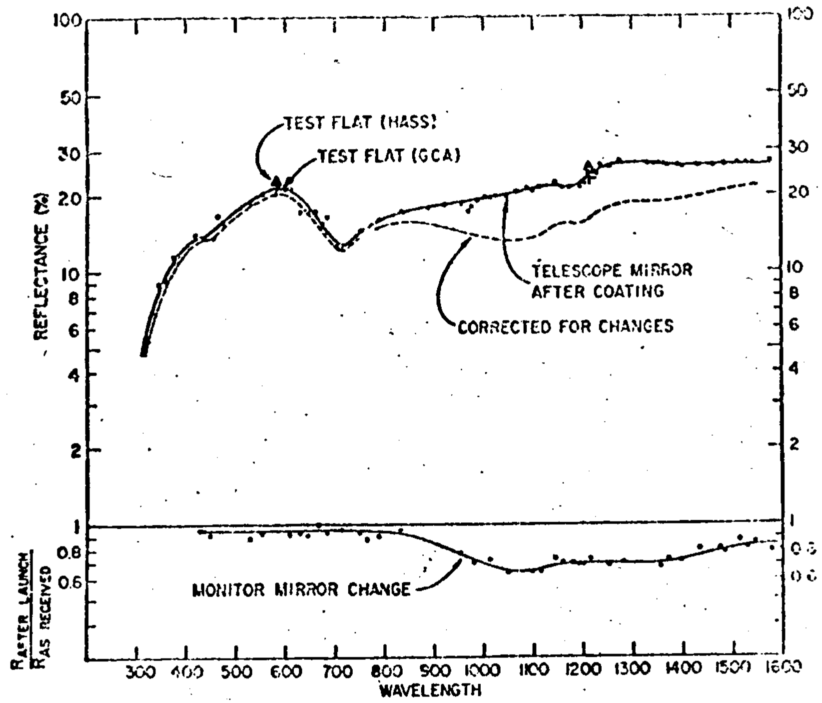
Pt REFLECTIVITY

FIGURE 1

STORAGE EFFECTS ON PLATINUM COATED OPTICS

Optical efficiency degradation of platinum coated optics stored in a Class 100 clean room and exposed to ultraviolet radiation.

(Reeves, et al., Harvard College, 1968)



Pt Reflectivity

FIGURE 2

OSO-IV MIRROR EFFICIENCY PRELAUNCH DEGRADATION

Reflectance comparison of monitor mirror taken from Harvard OSO-IV instrument only hours before launch and mirror shortly after it was coated. (Reeves, et al., Harvard College, 1968)

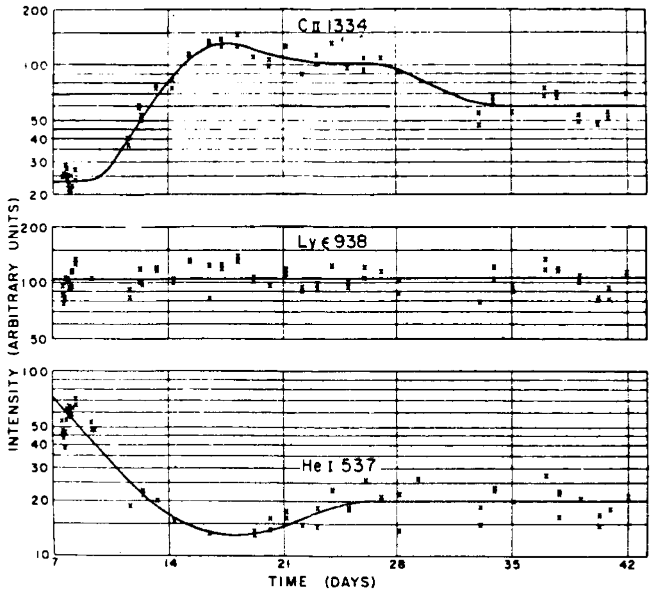
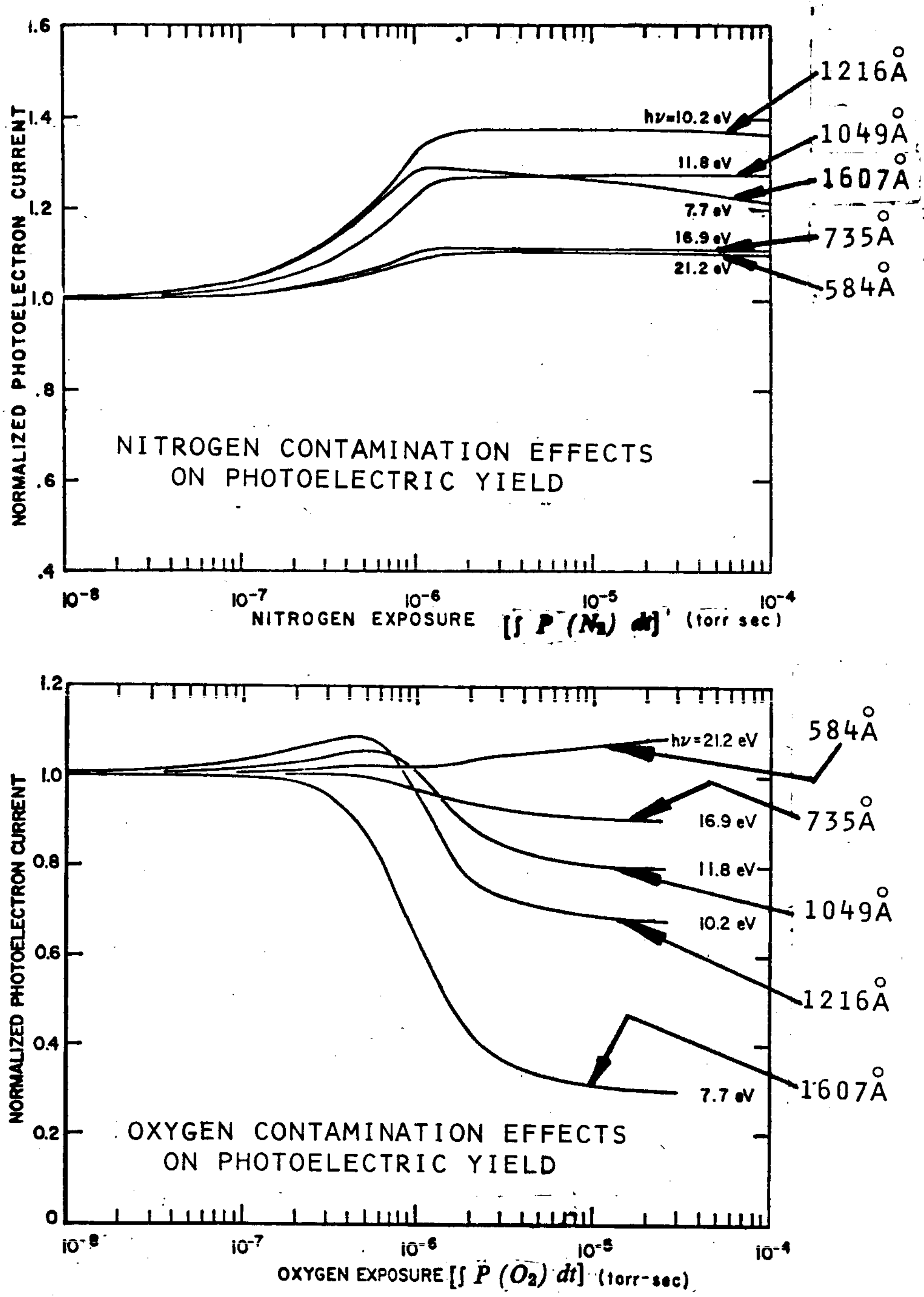


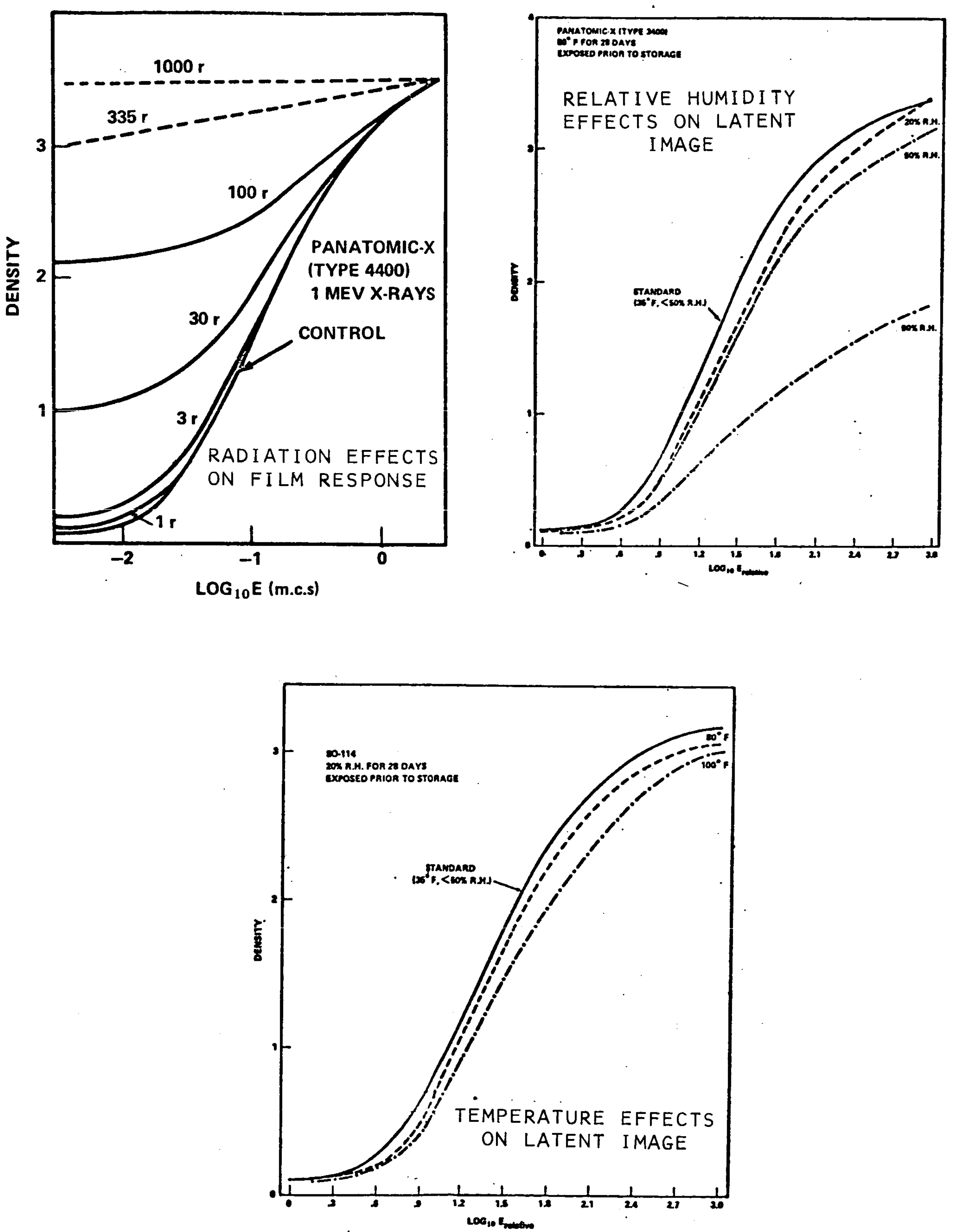
FIGURE 3. SENSITIVITY CHANGES IN THE HARVARD COLLEGE OBSERVATORY INSTRUMENT ON OSO-IV (REEVES, ET AL., MAY 1970)

FIGURE 4. CONTAMINATION EFFECTS ON PHOTOELECTRIC YIELD OF TUNGSTEN



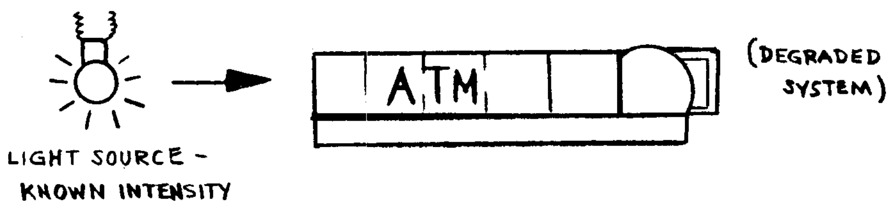
ATOMICALLY CLEAN POLYCRYSTALLINE TUNGSTEN AT 2700°K AND 1 TO 2 X 10^{-10} TORR IS EXPOSED TO SMALL CONTROLLED AMOUNTS OF CONTAMINATING GASES. PHOTOELECTRON CURRENT OUTPUT IS NORMALIZED TO MEASUREMENTS ON CLEAN TUNGSTEN TAKEN AT 2700°K AND 10^{-10} TORRS. (MADDEN, <u>ET AL</u>., 1968)

FIGURE 5. ENVIRONMENTAL DEGRADATION OF PHOTOGRAPHIC FILM



B. <u>METHODS</u>

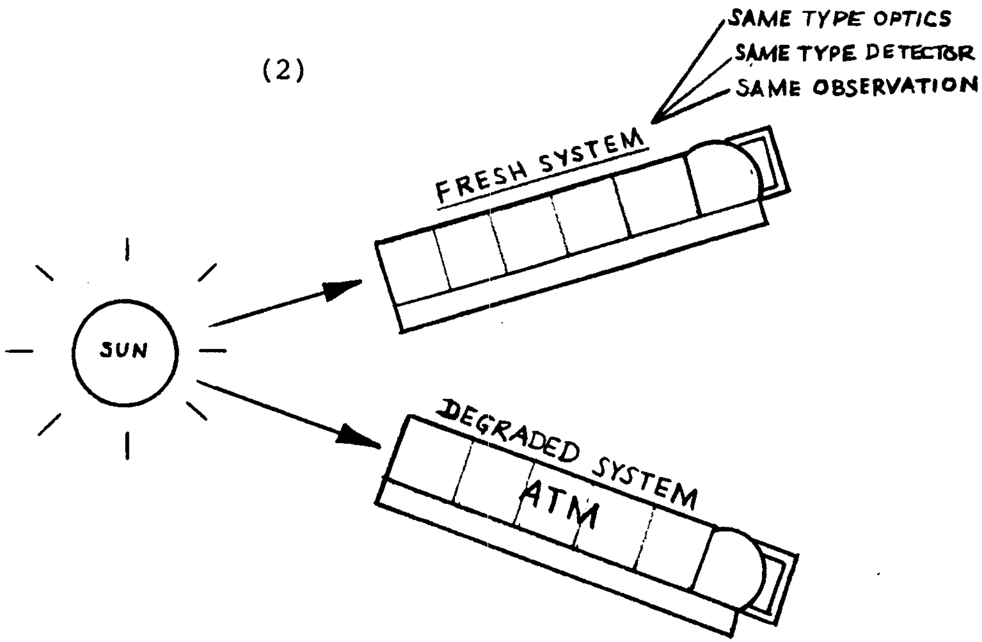
(1)



ARTIFICIAL SOURCE

USE STABLE SOURCE OF KNOWN INTENSITY OVER THE FULL WAVELENGTH RANGE OF THE INSTRUMENT; COMPARE DATA OBTAINED BEFORE THE MISSION (ON FRESH SYSTEM) WITH FLIGHT DATA (DEGRADED SYSTEM) USING SAME SOURCE.

(2)

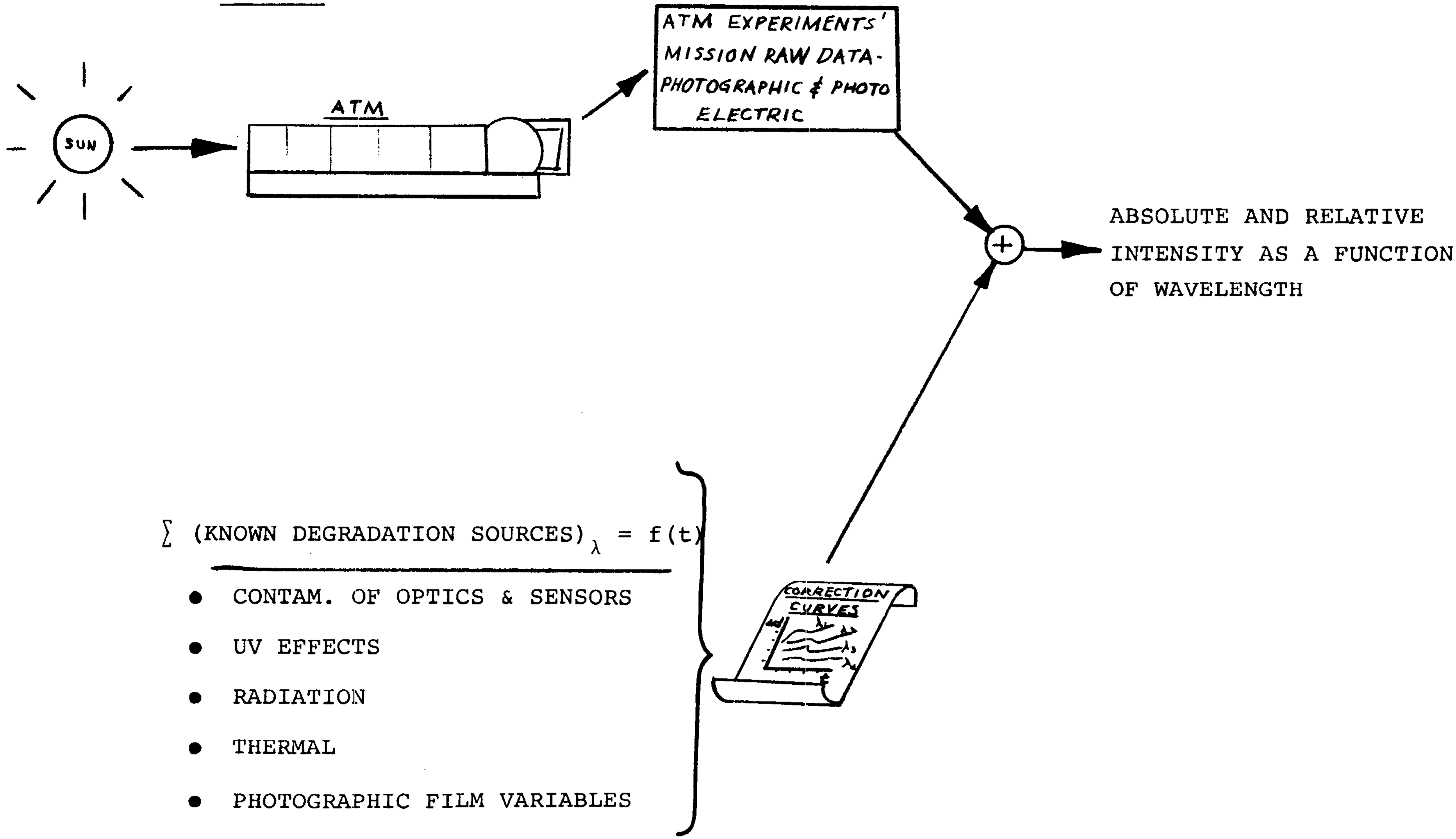


ASTRONOMICAL SOURCE

SIMULTANEOUSLY OBSERVE SUN WITH FRESH SYSTEM (NO DEGRADATION) AND THE ATM SYSTEM (DEGRADED SYSTEM) & COMPARE DATA

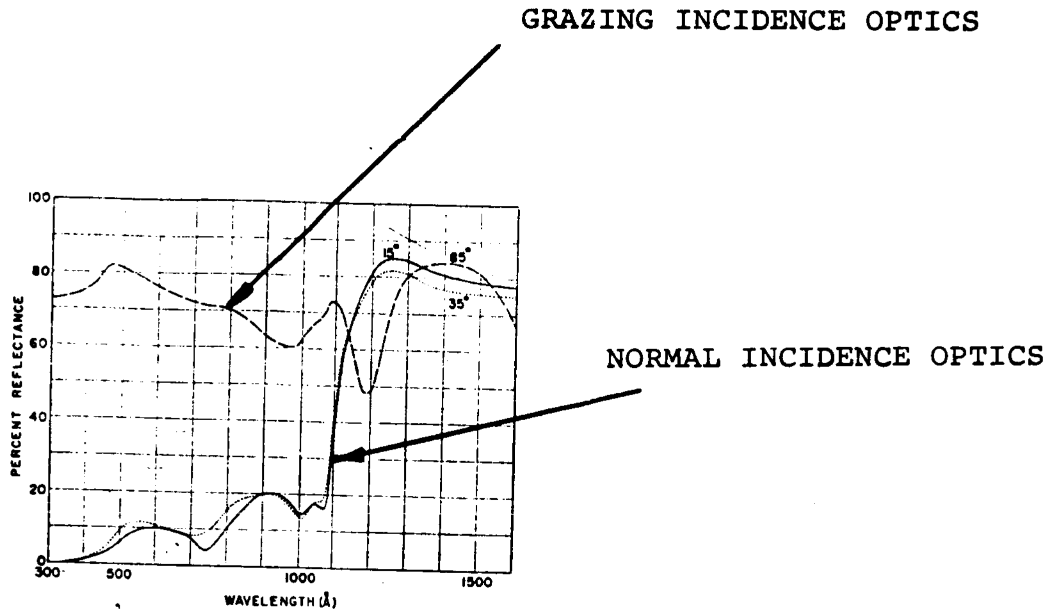
CALIBRATION -- HOW?

A. THE JOB --



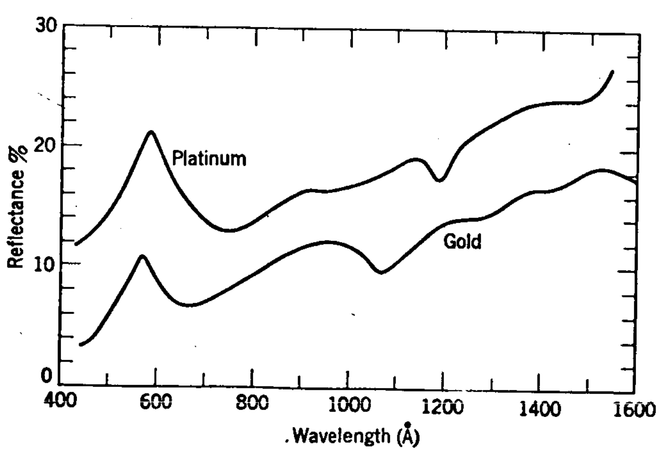
ATM EXPERIMENTS - PHYSICAL CHARACTERISTICS

EXPERIMENT NO.	TITLE	OPTICS TYPE	DETECTOR TYPE
S055	UV POLYCHROMATOR SPECTROHELIOMETER (GOLBERG) 300 - 1400Å	NORMAL INCIDENCE -- MIRROR -- PLATINUM & IRRIDIUM GOLD RULED-GRATING	OPEN CHANNEL ELECTRON MULTIPLIERS (7) -- PHOTOMULTIPLIERS
S082A	CORONAL SPECTRO-HELIOGRAPH XUV (TOUSEY) 150 - 625Å	NORMAL INCIDENCE GRATING - GOLD RULED	FILM SWR
S082B	CHROMOSPHERIC XUV SPECTROGRAPH (TOUSEY) 970 - 1970Å 1940 - 3940Å	NORMAL INCIDENCE -- MIRROR -- $Al+MgF_2$ MAIN GRATING -- $Al+Al+MgF_2$ PREDISP. GRATING -- $Al+Al+MgF_2$ PREDISP. GRATING -- $Al+ZnS+Al+ZnS$	FILM SWR



Measured reflectance of an Al + MgF_2 mirror from 300 Å to 1600 Å. The MgF_2 thickness is 250 Å.

(W. Hunter & G. Hass, 1971)



Normal incidence reflectance of Au and Pt as a function of wavelength.

(J. A. R. Samson, 1967)

FIGURE 6. REFLECTANCE OF ATM-TYPE OPTICAL ELEMENTS

OTHER SKYLAB UV EXPERIMENTS - PHYSICAL CHARACTERISTICS

EXPERIMENT NO.	TITLE	OPTICS - TYPE	DETECTOR - TYPE
S019	UV STELLAR ASTRON. (HENIZE) 1400 - 3000Å	MIRRORS(3) - $Al+MgF_2$ PRISM - CaF_2 FIELD CORRECTORS - CaF_2 LiF ARTICULATED MIRROR - $Al+MgF_2$	FILM(UV) 101-06
S020	UV X-RAY SOLAR ASTRON. (TOUSEY) 10 - 100Å 20 - 200Å	GRATING - Al+Pt (GRAZING INCIDENCE) FILTERS - INDIUM, BERYLLIUM	FILM 101-06
S063*	UV AIRGLOW HORIZON PHOTOGRAPHY (PACKER) 2600, 2800, 3200, 3914, 5577, & 6300Å	UV WINDOW 2400 - 5900Å AND BANDPASS FILTERS	FILM 2485 AND S0368 (VISIBLE COLOR)
S183	UV PANORAMA (COURTES & LAGET) 1500 - 2100Å 2800 - 3400Å	MIRRORS(3) - $Al+MgF_2$ GRATING - $Al+MgF_2$	FILM SC-5 (UV) AND 103αO (UV)

*NOT REALLY APPLICABLE.

SUMMARY -- THE INADEQUACY OF USING OTHER SKYLAB EXPERIMENTS FOR ATM ULTRAVIOLET EXPERIMENT DATA CALIBRATION

STELLAR/SKY MONITORING EXPERIMENTS (S019, S063, & S183)

- UV SOURCES VERY DIM -- ATM EXPERIMENT EXPOSURE TIMES INCOMPATIBLE
- STELLAR SOURCES ARE POINT SOURCES AND WILL NOT FILL ATM EXPERIMENT SLITS
- ATM T.V. RESOLUTION INSUFFICIENT FOR BORESIGHTING OF STELLAR SOURCES
- FINE POINTING SYSTEM CAGED WHEN NOT POINTED AT THE SUN, AND CMG SYSTEM NOT ACCURATE ENOUGH TO PLACE A STAR WITHIN THE EXPERIMENTS SLITS (6 MIN ACCURACY)
- FILM AND OPTICAL SYSTEMS ALL ARE DIFFERENT FROM ATM
- DATA AND DETECTORS WILL DEGRADE WITH TIME ALONG WITH ATM
- FULL WAVELENGTH RANGE UNAVAILABLE
- EXPERIMENTS S019 AND S183 MOUNTED IN THE ANTI-SOLAR SAL -- STUDY REQUIRED TO DETERMINE EFFECT OF MOUNTING IN THE SOLAR SAL (TIMELINE, THERMAL, ETC.)

SOLAR EXPERIMENT (S020)

- INSUFFICIENT WAVELENGTH RANGE -- DOES NOT COVER WAVELENGTHS OF MOST MARKED DEGRADATION
- OPTICS AND FILM DIFFERENT AND WILL DEGRADE WITH TIME

ULTRAVIOLET CALIBRATION SOURCES FOR ATM IMPLEMENTATION COMMENTS

SOURCE	COMMENTS
1. THE SUN	• PROVIDES TOTAL UV RANGE OF ATM INSTRUMENTS WITH HIGH INTENSITY LINE SPECTRA & CONTINUUM • INTENSITIES VARY WITH TIME, THEREFORE THE PERMANENCE OF THE STANDARD IS DESTROYED • DETERMINATION OF INSTRUMENT AND DETECTOR DEGRADATION MUST BE DONE BY OBSERVING IDENTICAL SOLAR AREAS AT THE SAME TIME (IDENTICAL SOURCE INTENSITIES) WITH FRESH DETECTORS AND OPTICS
2. STARS	• PROVIDES LOW INTENSITY POINT SOURCES FROM 900-4000Å. UV OPTICAL REFLECTANCES OF ATM WILL WIPE OUT SHORTER WAVELENGTHS OF INTEREST (E.G. SOLAR RADIANT ENERGY AT $\lambda < 1000Å = .0001\% \times$ TOTAL SOLAR ENERGY) • ATM FILM EXPOSURE TIMES UNADJUSTABLE • SOURCES (STARS) WILL NOT FILL FIELD-OF-VIEW OF EXPERIMENTS • POINTING PROBLEMS
3. ARTIFICAL LIGHT SOURCES -- GENERAL	• ALL UV LIGHT SOURCES ARE LABORATORY-TYPE SOURCES AND WOULD REQUIRE FLIGHT QUALIFICATION • SOURCES WOULD REQUIRE CALIBRATION AGAINST STANDARDS, PERIODICALLY • WAVELENGTHS <1050Å REQUIRE WINDOWLESS DEVICES AND DIFFERENTIAL PUMPING SYSTEMS

SOURCE	COMMENTS
3. ARTIFICIAL LIGHT SOURCES -- GENERAL (CONTINUED)	• DISCHARGE (GLOW, ARC, AND SPARK) SOURCES REQUIRE HIGH-VOLTAGE/HIGH-CURRENT POWER SUPPLIES • INCORPORATION OF ARTIFICIAL LIGHT SOURCES IN ATM INSTRUMENTS (S082 & S055) NOT POSSIBLE AT THIS STAGE OF THE PROGRAM • IMPLEMENTATION EXTERNAL TO INSTRUMENTS DIFFICULT, WOULD INVOLVE ASTRONAUT TASKS (EVA) AND MAY BE EXTREMELY HAZARDOUS (HIGH VOLTAGE SOURCES, ELECTRICAL INTERFACES, TOXIC & HAZARDOUS HIGH ENERGY GAS SUPPLIES, AND GLASS TUBES) • EMI GENERATION HIGH -- REQUIRES STUDY
A. HYDROGEN-GLOW DISCHARGE	• REPRODUCIBLE STABLE SOURCE FROM 500 TO 5000Å CURRENTLY UNDER DEVELOPMENT BY NBS • HYDROGEN GAS SUPPLY REQUIRED WITH WINDOWLESS DEVICE -- CONTAM. & HAZARDS • ∿300MA@∿700V POWER SUPPLY REQUIRED
B. SYNCHROTRON	• GROUND BASED FACILITY -- NOT APPLICABLE
C. RARE GAS-CONDENSED SPARK DISCHARGE (HELIUM, NEON, ARGON, KRYPTON, & XENON) & MICROWAVE CAVITIES	• MULTIPLE GAS SUPPLIES REQUIRED • NOT VERY UNIFORM, STEADY, OR REPRODUCIBLE • ∿116MA@10KV POWER SUPPLY REQUIRED -- SPARK DISCHARGE 2450MHZ ∿800W REQUIRED -- MICROWAVE SOURCE

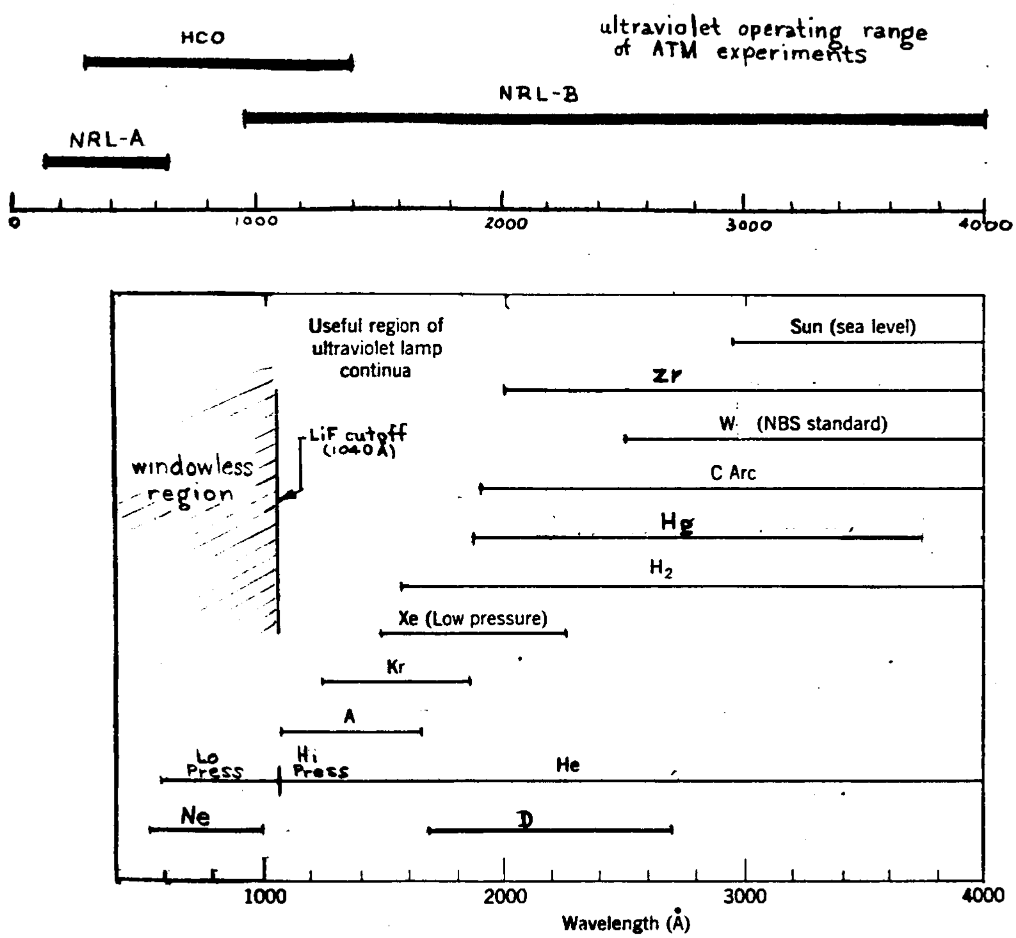
SOURCE	COMMENTS
D. FLASH TUBE	• GAS SUPPLY REQUIRED • ACTIVE COOLING REQUIRED . . . CONTAMINATION SOURCE • PULSED DISCHARGES NOT SUITABLE FOR FILM (INTERMITTENCY EFFECT ~ RECIPROCITY FAILURE) ~90KA/CM^2 @10KV POWER SUPPLY
E. TUNGSTEN STRIP LAMP (COIL AND RIBBON)	• ONLY COVERS WAVELENGTH >2500Å • LIFE DROPS RADICALLY WITH TEMPERATURE INCREASE
F. XENON AND MERCURY ARCS (SHORT ARC)	• ONLY COVER 1480 - 2000Å AND 1900 - 3750Å WAVELENGTH RANGES, RESPECTIVELY • HIGH CURRENT AND POWER REQUIREMENTS • UNSTABLE ARC, UN-UNIFORM, AND NOT REPRODUCIBLE • REQUIRES COOLING
G. COLD CATHODE DC GLOW DISCHARGE (H_2, He, Ar, Kr, Xe RESONANCE LINES), HUNTER-TYPE LAMP, & HOLLOW CATHODE ARC DISCHARGE (SCHULER OR PASCHEN-TYPE LAMP)	• REQUIRES GAS SUPPLIES • REQUIRES COOLING OF ELECTRODE (COOLANT SYSTEM) • REQUIRES HIGH VOLTAGE POWER SUPPLY 2KV @100-500MA-GLOW DISCHARGE; ~240 WATTS -- HUNTER LAMP • CATHODE MATERIALS, FOR HOLLOW CATHODE LAMP, MUST BE CHANGED FOR DIFFERENT WAVELENGTHS
H. HOT FILAMENT ARC AND DUOPLASMATRON	• EROSION OF ELECTRODE HIGH AND NON-UNIFORM TEMPERATURES ACROSS THE FILAMENT; SHORT LIFE -- HOT FILAMENT ARC • GAS SUPPLY REQUIRED • REQUIRES ~3A @~90V POWER SUPPLY -- HOT FILAMENT; ~600W -- DUOPLASMATRON

SOURCE	COMMENTS
I. ELECTRODE-LESS MICROWAVE LAMP	• WEAKER INTENSITIES THAN G, ABOVE • REQUIRES OSCILLATOR OR SPARK GENERATOR • $\sim$200W POWER SUPPLY REQUIRED @2450HZ
J. CONDENSED VACUUM OR LOW PRESSURE GAS SPARK DISCHARGE	• WAVELENGTHS <1000Å, POSSIBLE (OPEN WINDOW) • EMI FROM SOURCE AND SPARK GAP • SPUTTERING AND EROSION OF ELECTRODES & CONTAM. POTENTIAL • WATER COOLING OF ELECTRODES REQUIRED • HIGH VOLTAGE, HIGH-POWERED POWER SUPPLY 6-30KV @100MA REQUIRED • EMISSION LINE INTENSITY VARIES FROM SPARK TO SPARK
K. ČERENKOV RADIOACTIVE SOURCE OR SCINTILLATION PHOSPHORS	• RADIOACTIVITY • INSTABILITY OF SCINTILLATING MATERIAL • MECHANICAL SHUTTERS REQUIRED • MEAN LIGHT LEVEL LOW BUT INSTANTANEOUS LEVELS HIGH (LIGHT EMITTED IN CLUMPS OF PHOTONS)
L. CARBON ARC (LOW AND HIGH CURRENT)	• COVERS ONLY 1900 - 4000Å WAVELENGTH RANGE • HIGH CURRENT $\sim$60 - 200 AMPS/LOW CURRENT $\sim$10 AMPS @60 VOLTS • INTENSITY FLUCTUATIONS - UNSTABLE

Table 1

VACUUM ULTRAVIOLET LIGHT SOURCES

Continuum	Line Spectra
• H_2 GLOW DISCHARGE	• COLD CATHODE GLOW DISCHARGE
• RARE GAS GLOW DISCHARGE	DC GLOW DISCHARGE
CONDENSED SPARK	HUNTER LAMP
MICROWAVE EXCITATION	HOLLOW CATHODE - SCHULER LAMP
MICROWAVE CAVITY	• HOT FILAMENT ARC DISCHARGE
FLASH TUBE	• DUOPLASMATRON
• SYNCHROTRON	• MICROWAVE OR RF GLOW DISCHARGE
• BREMMSSTRAHLUNG -- X-RAY TUBE	• CONDENSED SPARK
• CARBON ARC	• LOW PRESSURE MERCURY ARC
LOW CURRENT ARC	• CADMIUM AND ZINC ARCS
HIGH CURRENT ARC	• PHOSPHORS - CaF_2, NaCl + AgCl, NaBr + AgCl
• COMPACT OR SHORT ARCS	• CERENKOV SOURCES
HYDROGEN OR DEUTERIUM ARC	• LASERS
Xe/Hg, Xe, OR Hg ARCS	
• ZIRCONIUM CONCENTRATED ARC	
• ARGON VORTEX STABILIZED ARC	
• INCANDESCENT SOURCES	
BLACKBODY SOURCES	
QUARTZ - IODINE TUNGSTEN COIL	
TUNGSTEN RIBBON	



Spectral regions of usable ultraviolet continua from present-day light sources.

FIGURE 7

CONCLUSIONS AND RECOMMENDATIONS

1. DEGRADATION OF UV OPTICS, FILM, AND OPEN CHANNEL PHOTOMULTIPLIERS IN THE SPACE ENVIRONMENT IS WELL KNOWN AND IS WAVELENGTH AND TIME DEPENDENT ..... SATELLITE PROGRAM EXPERIENCE.

2. ATM EXPERIMENT OPTICS WILL HAVE ACQUIRED CONSIDERABLE AGE, HANDLING, AND POTENTIAL FOR EXPOSURE TO CONTAMINANTS BETWEEN EXPERIMENT WAVELENGTH CALIBRATION AND THE END OF THE FLIGHT PROGRAM (>2-¾ - 3 YEARS) AND OPTICAL CHARACTERISTICS WILL PROBABLY CHANGE.

3. TO PROPERLY INTERPRET SCIENTIFIC DATA AND CONFIRM THEORIES, SOLAR SCIENTISTS BELIEVE ABSOLUTE CALIBRATION ACCURACY SHOULD BE WITHIN 10 - 20%.

4. TO FOLLOW THE WAVELENGTH CALIBRATION ACCURATELY WITH TIME IT IS NECESSARY TO FOLLOW STANDARD WAVELENGTHS AT LEAST AT 100Å INTERVALS (REEVES).

5. ABSOLUTE AND RELATIVE INTENSITY CALIBRATION OF ATM UV EXPERIMENTS OVER THE FULL WAVELENGTH RANGE DURING THE MISSION IS A NECESSARY FUNCTION.

6. AT THE PRESENT TIME, MULTIPLE LIGHT SOURCES ARE USED FOR ATM UV EXPERIMENT CALIBRATION IN THE LABORATORY. AVAILABLE STANDARD LIGHT SOURCES ARE NEITHER SUFFICIENTLY RELIABLE NOR CONTAIN LINE SPECTRA OR CONTINUUM WITH BROAD ENOUGH COVERAGE TO SERVE AS AN ABSOLUTE STANDARD FOR ATM. THEY ARE DIFFICULT TO USE, REQUIRE GAS SUPPLIES, REQUIRE CONSIDERABLE POWER, AND ARE NOT FLIGHT QUALIFIED.

7. SATELLITES OF COMPARABLE WAVELENGTH RANGES ALSO REQUIRE ABSOLUTE CALIBRATION AND USE ROCKET FLIGHT INSTRUMENTS (OSO, OGO, OAO, ETC.). SATELLITE EXPERIMENTS USE PHOTOELECTRIC UV SYSTEMS AND DIFFERENCES IN FIELDS-OF-VIEW, RESOLVING POWERS, INSTRUMENT CONFIGURATIONS, AND SIMULTANEOUS POINTING PROBLEMS MAKE COMPARISON OF ATM DATA TO CORRECTED SATELLITE DATA IMPRACTICAL.

CONCLUSIONS AND RECOMMENDATIONS (CONTINUED)

8. THE USE OF OTHER SKYLAB EXPERIMENTS FOR ATM CALIBRATION DOES NOT APPEAR PRACTICABLE (WAVELENGTH COVERAGE INSUFFICIENT, OPTICS/DETECTORS DIFFERENT AND ALSO DEGRADE WITH TIME, POINTING PROBLEMS, ETC.).

9. USE OF ARTIFICIAL LIGHT SOURCES NOT PRACTICABLE --

   - LINE SOURCES INADEQUATE TO FOLLOW WAVELENGTH DEPENDENT SHIFTS
   - UNSTABLE AND UNRELIABLE
   - SOURCE OVER THE FULL RANGE UNAVAILABLE
   - REQUIRES GAS SUPPLIES -- SAFETY
   - INCORPORATION INTERNAL TO ATM EXPERIMENT PACKAGE NOT POSSIBLE AT THIS TIME
   - EXTERNAL INCORPORATION DIFFICULT AND NOT PRACTICAL
   - REPRESENT LARGE EMI SOURCES FOR SKYLAB
   - FLIGHT QUALIFICATION REQUIRED.

10. RECOMMENDATIONS --

   A. ROCKET CALIBRATION INSTRUMENTS, WITH FRESH OPTICS AND SENSORS, ARE NECESSARY FOR COMPARISON AGAINST DEGRADED ATM DATA.

   B. FIVE ROCKET CALIBRATIONS WOULD BE HIGHLY DESIRABLE (SL-4:2, SL-3:2, SL-2:1), BUT THREE (ONE PER MISSION) WOULD BE BETTER THAN NONE AT ALL. (THIS COINCIDES WITH JOHNS HOPKINS UNIVERSITY CALIBRATION REVIEW RECOMMENDATIONS -- 10/20/70.)

   C. CONSIDER FLYING RETRIEVABLE OPTICAL SAMPLES IN THE ATM EXPERIMENT PACKAGE TO FURTHER CONFIRM DIFFERENCES BETWEEN CALIBRATION ROCKET DATA AND ATM DATA. CONSIDER FLYING RETRIEVAL OPTICAL SAMPLES THAT ARE EXPOSED TO THE SAME UV ENVIRONMENT, THERMAL ENVIRONMENT, AND CONTAMINATION ENVIRONMENT AS THE EXPERIMENTS ARE ON FUTURE UV EXPERIMENTS.

CONCLUSIONS AND RECOMMENDATIONS (CONTINUED)

10. RECOMMENDATIONS (CONTINUED) --

D. CONSIDER EXTENDING EFFORTS BY THE NATIONAL BUREAU OF STANDARDS IN DEVELOPMENT OF A STANDARD UV SOURCE TO INCLUDE STUDIES THAT WILL DETERMINE HOW THE SOURCE CAN BE ADAPTED FOR IN-FLIGHT CALIBRATIONS ON FUTURE PROGRAMS.

E. FUTURE LONG TERMED MANNED EXPERIMENT PROGRAMS THAT INCLUDE UV INSTRUMENTS SHOULD CONSIDER RESUPPLY OF EXPERIMENT OPTICS AND DETECTORS (FILM AND PHOTOELECTRIC) WITH FRESH SUPPLIES DURING THE COURSE OF THE MISSION. THIS WOULD ALSO IMPROVE PRE-FLIGHT AND IN-FLIGHT MAINTAINABILITY OF EXPERIMENTS.

11. IT IS UNDENIABLE THAT ROCKET CALIBRATION INSTRUMENTS WILL OBTAIN SOLAR SCIENTIFIC DATA. SINCE THE FIELDS-OF-VIEW AND THE SPECTRAL AND SPATIAL RESOLUTIONS OF THE PROPOSED INSTRUMENTS ARE SIMILAR TO THE ATM INSTRUMENTS AND SINCE THE EVENTS OBSERVED ARE HOPEFULLY THE SAME AS ON ATM, THE SCIENCE WILL UNDOUBTEDLY DUPLICATE AND CONFIRM A <u>SMALL PORTION</u> OF THE DATA THAT WILL BE ACQUIRED BY ATM INSTRUMENTS. FAILURE OF ATM -- OR INABILITY TO RETURN ATM DATA WOULD ALLOW THE CALIBRATION INSTRUMENTS TO FLY AND RETURN UNIQUE SCIENTIFIC DATA, BUT THIS WOULD SERVE AS A <u>VERY POOR</u> SUBSTITUTE FOR ATM EXPERIMENTATION (300 SECS VS. SEVERAL HUNDRED HOURS OVER AN EIGHT-MONTH PERIOD) .....

Subject: In-Flight Calibration of Apollo Telescope Mount Experiments Operating in the Vacuum Ultraviolet (UV) Wavelength Range - Case 620

From: S. H. Levine

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